

This Page Is Inserted by IFW Operations
and is not a part of the Official Record

BEST AVAILABLE IMAGES

Defective images within this document are accurate representations of the original documents submitted by the applicant.

Defects in the images may include (but are not limited to):

- BLACK BORDERS
- TEXT CUT OFF AT TOP, BOTTOM OR SIDES
- FADED TEXT
- ILLEGIBLE TEXT
- SKEWED/SLANTED IMAGES
- COLORED PHOTOS
- BLACK OR VERY BLACK AND WHITE DARK PHOTOS
- GRAY SCALE DOCUMENTS

IMAGES ARE BEST AVAILABLE COPY.

**As rescanning documents *will not* correct images,
please do not report the images to the
Image Problem Mailbox.**



Europäisches Patentamt
European Patent Office
Office européen des brevets



(11) **EP 0 848 294 B1**

(12) **EUROPEAN PATENT SPECIFICATION**

(45) Date of publication and mention
of the grant of the patent:
19.09.2001 Bulletin 2001/38

(51) Int Cl.7: **G03F 7/038**, G03F 7/075,
G03C 9/08

(21) Application number: **97203898.8**

(22) Date of filing: **12.12.1997**

(54) **Photo-curable resin composition used for photo-fabrication of three-dimensional objects**

Photohärtbare Harzzusammensetzung zur Verwendung zum Photo-Herstellen dreidimensionaler
Objekte

Composition de résine photodurcissable utilisée pour la photofabrication d'objets en trois dimensions

(84) Designated Contracting States:
BE CH DE ES FI FR GB IT LI NL SE

• **Ukachi, Takashi**
Ushiku, Ibaraki 300-12 (JP)

(30) Priority: **13.12.1996 JP 35289396**

(74) Representative:
den Hartog, Jeroen Hendrikus Joseph et al
DSM Patents & Trademarks
Office Geleen
P.O. Box 9
6160 MA Geleen (NL)

(43) Date of publication of application:
17.06.1998 Bulletin 1998/25

(73) Proprietors:
• **DSM N.V.**
6411 TE Heerlen (NL)
• **JAPAN SYNTHETIC RUBBER CO., LTD.**
Tokyo 104 (JP)
• **Japan Fine Coatings Co., Ltd.**
Tokyo 104-8410 (JP)

(56) References cited:
EP-A- 0 535 828 **EP-A- 0 732 625**
WO-A-96/30182

(72) Inventors:
• **Yamamura, Tetsuya**
Tsukuba, Ibaraki 305 (JP)
• **Watanabe, Tsuyoshi**
Tsukuba, Ibaraki 305 (JP)
• **Takeuchi, Akira**
Tsuchiura, Ibaraki 300 (JP)

• **NUYKEN O ET AL: "OXETANE
PHOTOPOLYMERIZATION - A SYSTEM WITH
LOW VOLUME SHRINKAGE"**
MACROMOLECULAR SYMPOSIA, vol. 107, April
1996, pages 125-138, XP000625140
• **PATENT ABSTRACTS OF JAPAN vol. 096, no.**
010, 31 October 1996 -& JP 08 143806 A
(TOAGOSEI CO LTD), 4 June 1996,

Note: Within nine months from the publication of the mention of the grant of the European patent, any person may give notice to the European Patent Office of opposition to the European patent granted. Notice of opposition shall be filed in a written reasoned statement. It shall not be deemed to have been filed until the opposition fee has been paid. (Art. 99(1) European Patent Convention).

EP 0 848 294 B1

Description**Field of the Invention**

- 5 [0001] The present invention relates to a photo-curable resin composition used for photo-fabrication of three-dimensional objects.

BACKGROUND OF THE INVENTION

- 10 [0002] In recent years, photo-fabrication processes for forming three-dimensional objects consisting of integrally laminated cured resin layers prepared by repeating a step of forming a cured resin layer by selectively irradiating a liquid photo-curable material with light have been proposed (see Japanese Patent Application Laid-open No. 247515/1985, USP No. 4,575,330 (Japanese Patent Application Laid-open No. 35966/1987), Japanese Patent Application Laid-open No. 101408/1987, Japanese Patent Application Laid-open No. 24119/1993).

- 15 [0003] A typical example of such a photo-fabrication process comprises forming a curable resin layer having a specified pattern by selectively irradiating with light using, for example, an ultraviolet radiation laser on the surface of a liquid photo-curable material (photo-curable resin composition) in a container, feeding the photo-curable resin composition equivalent to one layer to form another thin layer of the composition over this cured resin layer, and selectively irradiating this thin layer with light to form a new cured resin layer which is integrally laminated over the previously formed cured resin layer. This step is repeated a number of times, with or without changing the pattern in which the light is irradiated to form a three-dimensional object consisting of integrally laminated multiple cured resin layers. This photo-fabrication process has been attracting considerable attention, because the target three-dimensional object can easily be prepared in a short period of time even if it has a complicated shape.

- 20 [0004] EP 0 732 625 A and EP 0 535 282 A disclose photocurable resin compositions comprising oxetanes which are used in stereolithography baths.

- 25 [0005] JP 08 143806 A discloses a composition comprising oxetane compounds. The composition is used as an ink curable by actinic radiation.

- [0006] The following resin compositions (A) to (C) represent photo-curable resin compositions conventionally used in the photo-fabrication process.

- 30 (A) Resin compositions containing a radically polymerizable organic compound such as urethane(meth)acrylate, oligoester(meth)acrylate, epoxy(meth)acrylate, thiol-ene compounds, photosensitive polyimide, and the like (see Japanese Patent Applications Laid-open No. 204915/1989, No. 208305/1990, and No. 160013/1991).

- 35 (B) Resin compositions containing a cationically polymerizable organic compound such as an epoxy compound, cyclic ether compound, cyclic lactone compound, cyclic acetal compound, cyclic thioether compound, spiro-orthoester compound, vinyl ether compound, and the like (see Japanese Patent Application Laid-open No. 213304/1989).

- 40 (C) Resin compositions containing a radically polymerizable organic compound and a cationically polymerizable organic compound (see Japanese Patent Applications Laid-open No. 28261/1990, No. 75618/1990, and No. 228413/1994).

- 45 [0007] The characteristics required of the photo-curable resin composition used for these photo-fabrication processes include a low viscosity to quickly form a smooth liquid surface and the capability of being rapidly cured by irradiation with light. Also, the required characteristics of the photo-curable resin composition are minimal swelling of the cured products and minimal deformation due to shrinkage during curing with light, so as to minimize the production of defective parts such as warped parts, indented parts (sinkmark), or stretched parts (overhanging parts).

- [0008] Three-dimensional objects prepared by photo-fabrication methods have conventionally been used for design model, trial mechanical parts for confirming the functionality, or masters for molds. In order to use this process for trial mechanical parts, it is important that the three-dimensional object has high dimensional accuracy in accordance with the design in fine processing, mechanical strength and heat resistance sufficient to withstand conditions of use.

- 50 [0009] However, no conventional resin composition can satisfy the above demands. The three-dimensional objects obtained, for example, from the above-mentioned resin composition (A), which is a resin composition containing a radical polymerizable organic compound, such as urethane(meth)acrylate, oligoester(meth)acrylate, or epoxy(meth)acrylate, exhibit problems of deformation with the passage of time, such as production of warped parts, or indented parts, or stretched parts (overhanging parts), because of residual strain due to the shrinkage during curing. These problems of deformation with the passage of time can be partly solved by the correction of the input data to the CAD. However, CAD corrections are insufficient to compensate for modern trial mechanical parts which have intricate and complicated shapes, or for circumstantial variations of use.

[0010] The above-mentioned conventional resin composition (B) include cationically photo-polymerizable compound containing an epoxy compound have drawbacks that the photo-curing rate of the resin solution is lower than that of resin compositions including a radically photo-polymerizable compound in photo-fabrication processes, necessitating the processing time to be prolonged. Also, three-dimensional objects prepared by photo-fabrication using resin compositions including a cationically photo-polymerizable compound containing a conventionally known epoxy compound are not provided with sufficient toughness required for the trial mechanical parts used for confirming the functionality.

[0011] Only an insufficient photo-curing rate can be provided using even hybridized photo-curing resin compositions including, for example, (meth)acrylate monomer which is the above-mentioned radically photo-polymerizable compound (C), and an epoxy compound which is a cationically photo-polymerizable compound.

[0012] The present invention has been achieved in view of this situation and has an object of providing a photo-curable resin composition used for photo-fabrication, which can be rapidly cured to ensure reduction in the period of time required for photo-fabrication processes. Also, the present invention has an object of providing a photocurable composition used for photo-fabrication, which can provide three-dimensional objects which have high toughness and dimensional accuracy.

SUMMARY OF THE INVENTION

[0013] The above object can be attained in the present invention by a process with a photo-curable resin composition used for photo-fabrication of three-dimensional objects comprising,

- (A) an oxetane compound,
- (B) an epoxy compound, and
- (C) a cationic photo-initiator, as set out in claims 1 or 2.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] Figure is a front elevation view of a three-dimensional object for evaluating the fabricating capability of the resin compositions prepared in the Examples and the Comparative Examples.

DETAILED DESCRIPTION OF THE INVENTION AND PREFERRED EMBODIMENTS

[0015] The present invention will now be explained in detail.

(A) Oxetane compound

[0016] A compound having an oxetane ring (herein referred to as an oxetane compound) is employed as Component (A) of the photo-curable resin composition of the present invention. The oxetane compound of the present invention is a compound having one or more oxetane rings represented by the following formula (1). This compound can be polymerized or crosslinked by radiation from light in the presence of a cationic photo-initiator.

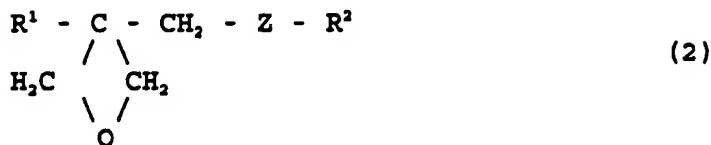


[0017] The oxetane compound may contain 1 or more oxetane groups. Preferably, the compound has less than 20, and in particular less than 10 oxetane groups. In particularly preferred embodiments the oxetane compound has two oxetane groups. It may also be useful to use mixtures of oxetane compounds, in particular those having 1, 2, 3, 4 or 5 oxetane groups.

[0018] The oxetane compound preferably has a molecular weight of about 100 or more, preferably of about 200 or more. Generally, this compound will have a molecular weight of about 10,000 or lower, preferably of about 5,000 or lower.

[0019] In one embodiment of the invention, the oxetane groups preferably constitute the terminus of radiation curable oligomers having a phenyl, (oligo)-bis-phenyl, polysiloxane or polyether, backbone. Examples of polyethers are e.g. poly-THF, polypropylene glycol, alkoxyated trimethylolpropane, alkoxyated pentaerythritol and the like.

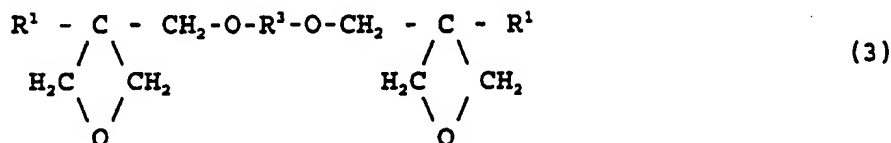
[0020] Preferably, the oxetane compound has one or more groups according to formula (2)



in which Z is oxygen or sulfur, most preferably oxygen, and in which R¹ and R² constitute the remainder of a molecule.

[0021] Examples of the compound having one oxetane ring used as component(A) are the compounds represented by the above formula (2), wherein Z represents an oxygen atom or a sulfur atom, R¹ represents a hydrogen atom; fluorine atom; alkyl group having from 1 to 6 carbon atoms such as for example a methyl group, ethyl group, propyl group, butyl group; fluoroalkyl group having from 1 to 6 carbon atoms such as for example a trifluoromethyl group, perfluoroethyl group, perfluoropropyl group; aryl group having from 6 to 18 carbon atoms such as for example a phenyl group, naphthyl group; furyl group, or thienyl group, and R² represents a hydrogen atom, alkyl group having from 1 to 6 carbon atoms such as for example a methyl group, ethyl group, propyl group, butyl group; alkenyl group having from 2 to 6 carbon atoms such as for example an 1-propenyl group, 2-propenyl group, 2-methyl-1-propenyl group, 2-methyl-2-propenyl group, 1-butenyl group, 2-butenyl group, 3-butenyl group; aryl group having from 6 to 18 carbon atoms such as for example a phenyl group, naphthyl group, anthonyl group, phenanthryl group; aralkyl group having from 7 to 18 carbon atoms which may be either substituted or unsubstituted, such as for example a benzyl group, fluorobenzyl group, methoxybenzyl group, phenethyl group, styryl group, cinnamyl group, ethoxybenzyl group; group having other aromatic groups such as for example an aryloxyalkyl group including a phenoxymethyl group, phenoxyethyl group; alkylcarbonyl group having from 2 to 6 carbon atoms such as for example an ethylcarbonyl group, propylcarbonyl group, butylcarbonyl group; alkoxy carbonyl group having from 2 to 6 carbon atoms such as for example an ethoxycarbonyl group, propoxycarbonyl group, butoxycarbonyl group; or N-alkylcarbamoyl group having from 2 to 6 carbon atoms such as for example an ethylcarbamoyl group, propylcarbamoyl group, butylcarbamoyl group, pentylcarbamoyl group.

[0022] The oxetane compounds having two oxetane rings, include for example those compounds represented by the following formula (3):



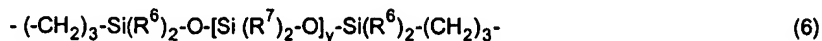
wherein R¹ independently represents a group represented by R¹ in formula (2), R³ represents a linear or branched alkylene group having from 1 to 20 carbon atoms such as for example an ethylene group, propylene group, butylene group; linear or branched poly(alkylenoxy) group having from 1 to 120 carbon atoms such as for example poly(ethyleneoxy) group, poly(propyleneoxy) group; linear or branched unsaturated hydrocarbon group such as for example a propenylene group, methylpropenylene group, butenylene group; carbonyl group, alkylene group containing a carbonyl group, alkylene group containing a carboxyl group in the middle of a molecular chain, and alkylene group containing a carbamoyl group in the middle of a molecular chain. Also, in the formula (3), R³ may be a polyvalent group represented by any one of the following formulas (4)-(6).



wherein Ø represents phenyl ring, R⁴ represents an alkyl group having from 1 to 4 carbon atoms such as for example a methyl group, ethyl group, propyl group, butyl group; alkoxy group having from 1 to 4 carbon atoms such as for example a methoxy group, ethoxy group, propoxy group, butoxy group; halogen atom such as for example a chlorine atom, bromine atom; nitro group, cyano group, mercapto group, lower alkylcarboxyl group, carboxyl group, or carbamoyl group, and x is an integer of from 0 to 4.



wherein R^5 represents an oxygen atom, sulfur atom, methylene group, and groups represented by the formulae $-\text{NH}-$, $-\text{SO}-$, $-\text{SO}_2-$, $-\text{C}(\text{CF}_3)_2-$, or $-\text{C}(\text{CH}_3)_2-$.

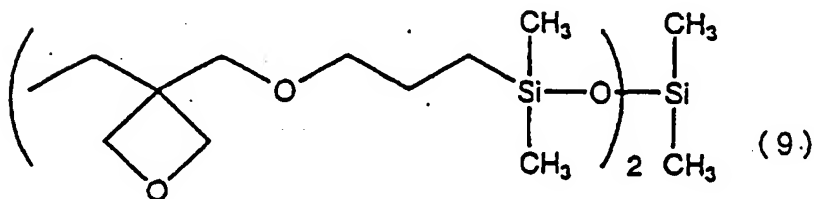
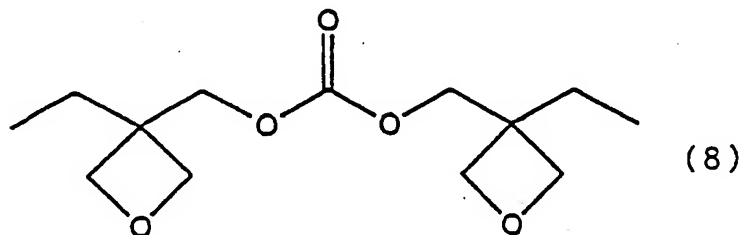


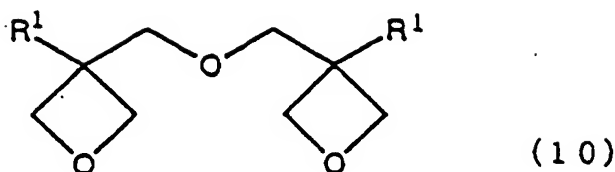
wherein R^6 represents an alkyl group having from 1 to 4 carbon atoms such as for example a methyl group, ethyl group, propyl group, butyl group, or aryl group having from 6 to 18 carbon atoms such as for example a phenyl group, naphthyl group, y denotes an integer of from 0 to 200, and R^7 represents an alkyl group having from 1 to 4 carbon atoms such as for example a methyl group, ethyl group, propyl group, butyl group or aryl group having from 6 to 18 carbon atoms such as for example a phenyl group, naphthyl group. Alternatively, R^7 may be a group represented by the following formula (7).



wherein R^8 represents an alkyl group having from 1 to 4 carbon atoms such as for example a methyl group, ethyl group, propyl group, butyl group, or aryl group having from 6 to 18 carbon atoms such as for example a phenyl group, naphthyl group, and z is an integer of from 0 to 100.

[0023] Given as examples of the compounds having two oxetane rings are the compounds represented by the following formulas (8)-(10).



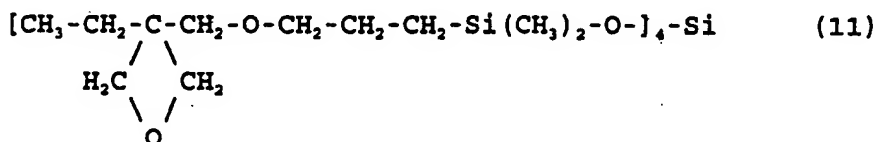


15 wherein R¹ represents the same group as defined in the formula (2).

[0024] As examples of compounds having three or more oxetane rings, the compounds represented by the formula (2) as described above, wherein R² is a polyfunctional organic group with a valence of from 3 to 10, such as linear or branched alkylene groups having from 1 to 30 carbon atoms or linear or branched disiloxane or polysiloxane groups. Suitable examples of polyfunctional compounds include linear or branched poly(alkyleneoxy) groups, for example, alkoxyated trimethylolpropane, or linear or branched polysiloxane containing groups with 2-10 dimethyl siloxane groups.

[0025] Examples of alkylene groups having a valence of 3 or more include trimethylol alkane in which the alkyl group has from 1 to 6 carbon atoms such as for example a methyl group, ethyl group, propyl group, pentaerythritol, dipentaerythritol and glucose.

25 [0026] Also, given as specific examples of the compounds having three or more oxetane rings are the compounds represented by the following formula (11).



[0027] Other useful compounds include polysiloxanes with pendant groups according to formula (2).

[0028] In addition to the above examples, the compound having oxetane rings used as component(A) may include compounds with a high molecular weight, e.g. a number average molecular weight reduced polystyrene of 1,000 to 5,000, measured using gel permeation chromatography. Examples of such compounds are compounds in which R¹ of formula (2) is e.g. methyl, ethyl or propyl, and in which R² is polyethyleneglycol with a polymerisation degree of between 20-200, compounds according to formula (3) in which R³ is polyTHF, or compounds which are based on alkoxyated pentaerythritol and the like.

[0029] Given as specific examples of the compounds having an oxetane ring used as component(A) are the following compounds:

45 Compounds having one oxetane ring

[0030] Typical examples of the compounds having one oxetane ring are as follows.

- 50
- 3-ethyl-3-hydroxymethyloxetane
 - 3-(meth)-allyloxymethyl-3-ethyloxetane
 - (3-ethyl-3-oxetanylmethoxy)methylbenzene
 - 4-fluoro-[1-(3-ethyl-3-oxetanylmethoxy)methyl]benzene
 - 4-methoxy-[1-(3-ethyl-3-oxetanylmethoxy)methyl]-benzene

55

 - [1-(3-ethyl-3-oxetanylmethoxy)ethyl]phenyl ether
 - isobutoxymethyl(3-ethyl-3-oxetanylmethyl) ether
 - isobornyloxyethyl(3-ethyl-3-oxetanylmethyl) ether
 - isobornyl(3-ethyl-3-oxetanylmethyl) ether

- 2-ethylhexyl(3-ethyl-3-oxetanylmethyl) ether
- ethyldiethylene glycol (3-ethyl-3-oxetanylmethyl) ether
- dicyclopentadiene (3-ethyl-3-oxetanylmethyl) ether
- dicyclopentenyl(3-ethyl-3-oxetanylmethyl) ether
- 5 - dicyclopentenyl(3-ethyl-3-oxetanylmethyl) ether
- tetrahydrofurfuryl(3-ethyl-3-oxetanylmethyl) ether
- tetrabromophenyl(3-ethyl-3-oxetanylmethyl) ether
- 2-tetrabromophenoxyethyl(3-ethyl-3-oxetanylmethyl) ether
- tribromophenyl (3-ethyl-3-oxetanylmethyl) ether
- 10 - 2-tribromophenoxyethyl(3-ethyl-3-oxetanylmethyl) ether
- 2-hydroxyethyl(3-ethyl-3-oxetanylmethyl) ether
- 2-hydroxypropyl(3-ethyl-3-oxetanylmethyl) ether
- butoxyethyl (3-ethyl-3-oxetanylmethyl) ether
- pentachlorophenyl(3-ethyl-3-oxetanylmethyl) ether
- 15 - pentabromophenyl (3-ethyl-3-oxetanylmethyl) ether
- bornyl(3-ethyl-3-oxetanylmethyl) ether

Compounds having two or more oxetane rings

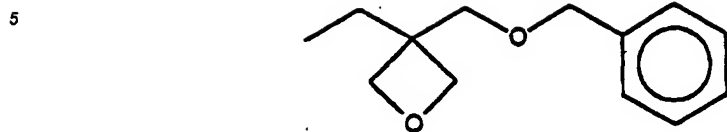
20 [0031] Typical examples of the compounds having two or more oxetane rings are as follows.

- 3,7-bis(3-oxetanyl) -5-oxa-nonane
- 3,3'-(1,3-(2-methylenyl)propanediylbis-(oxymethylene))-bis-(3-ethyloxetane)
- 1,4-bis[(3-ethyl-3-oxetanylmethoxy)methyl]benzene
- 25 - 1,2-bis[(3-ethyl-3-oxetanylmethoxy)methyl]ethane
- 1,3-bis[(3-ethyl-3-oxetanylmethoxy)methyl]propane
- ethylene glycol bis(3-ethyl-3-oxetanylmethyl) ether
- dicyclopentenylbis(3-ethyl-3-oxetanylmethyl) ether
- triethylene glycol bis(3-ethyl-3-oxetanylmethyl) ether
- 30 - tetraethylene glycol bis(3-ethyl-3-oxetanylmethyl) ether
- tricyclodecanediyl dimethylene bis(3-ethyl-3-oxetanylmethyl) ether
- trimethylolpropane tris(3-ethyl-3-oxetanylmethyl) ether
- 1,4-bis(3-ethyl-3-oxetanylmethyl)butane
- 1,6-bis(3-ethyl-3-oxetanylmethoxy)hexane
- 35 - pentaerythritol tris(3-ethyl-3-oxetanylmethyl) ether
- pentaerythritol tetrakis(3-ethyl-3-oxetanylmethyl) ether
- polyethylene glycol bis(3-ethyl-3-oxetanylmethyl) ether
- dipentaerythritol hexakis(3-ethyl-3-oxetanylmethyl)
- ether, dipentaerythritol pentakis(3-ethyl-3-oxetanylmethyl) ether
- 40 - dipentaerythritol tetrakis(3-ethyl-3-oxetanylmethyl) ether
- caprolactone modified dipentaerythritol hexakis(3-ethyl-3-oxetanylmethyl) ether
- caprolactone modified dipentaerythritol pentakis(3-ethyl-3-oxetanylmethyl) ether
- ditrimethylolpropane tetrakis(3-ethyl-3-oxetanylmethyl) ether
- EO modified bisphenol A bis(3-ethyl-3-oxetanylmethyl) ether
- 45 - PO modified bisphenol A bis(3-ethyl-3-oxetanylmethyl) ether
- EO modified hydrogenated bisphenol A bis(3-ethyl-3-oxetanylmethyl) ether
- PO modified hydrogenated bis(3-ethyl-3-oxetanylmethyl) ether
- EO modified bisphenol F bis(3-ethyl-3-oxetanylmethyl) ether

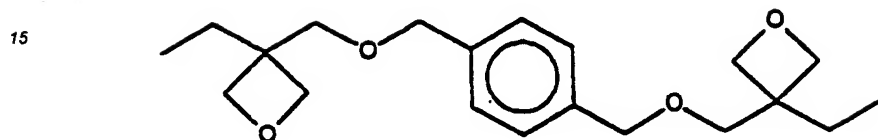
50 [0032] These compounds may be used either individually or in combinations of two or more.

[0033] Among these, preferred compounds having oxetane rings, which can be used as component (A) contained in the resin composition of the present invention, are (3-ethyl-3-oxetanylmethoxy)methylbenzene shown by the formula (12) illustrated below, 1,4-bis[(3-ethyl-3-oxetanylmethoxy)-methyl]benzene shown by the formula (13) illustrated below, 1,2-bis(3-ethyl-3-oxetanylmethoxy)ethane shown by the formula (14) illustrated below, trimethylolpropane tris(3-ethyl-3-oxetanylmethyl) ether shown by the formula (15) illustrated below, and the compounds represented by formula (16) shown below.

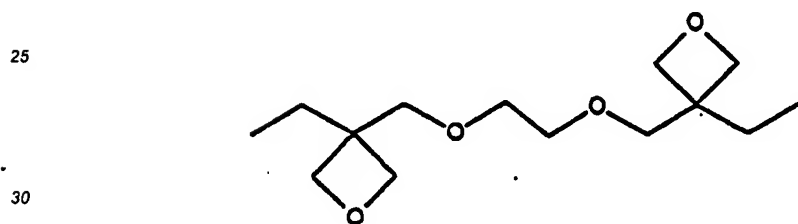
(12)



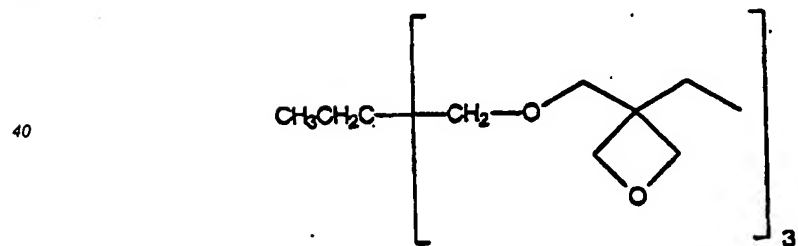
(13)

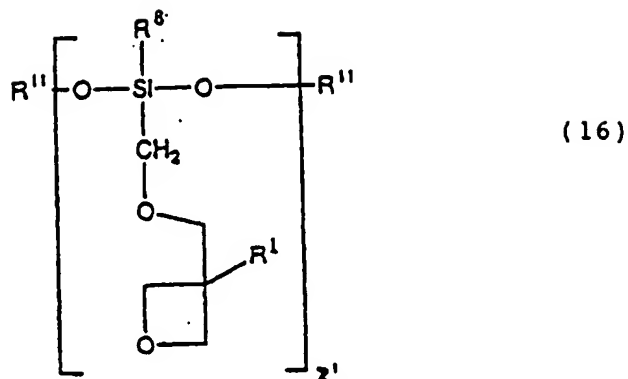


(14)



(15)





wherein R¹ represents the same group as defined in the formula (2), R⁸ represents the same group as defined in the formula (7), R¹¹ represents an alkyl group having from 1 to 4 carbon atoms such as for example a methyl group, ethyl group, propyl group, butyl group or a trialkylsilyl group, wherein the alkyl groups may be either the same or different and have from 3 to 12 carbon atoms, such as a trimethylsilyl group, triethylsilyl group, tripropylsilyl group, or tributylsilyl group, and z' is an integer from 1 to 10.

[0034] These compounds having oxetane rings may be used either individually or in combinations of two or more.

[0035] The proportion of component (A) in the resin composition of the present invention is usually 30-97% by weight, preferably 40-96% by weight, and more preferably 50-95% by weight. If the proportion of component (A) is too low, the rate (curing rate) of the cationic polymerization reaction is so reduced that molding time may be extended and the resolution may tend to be lower. On the other hand, if the proportion of component (A) is too high, there are tendencies that the toughness of the cured product is lower and the rate (curing rate) of the cationic polymerization reaction is reduced.

(B) Compound having an epoxy group

[0036] A compound having an epoxy group (herein referred to as an epoxy compound) is employed as Component (B) of the photo-curable resin composition of the present invention. Preferably, the epoxy compound of the present invention is a compound having an epoxy group and a number average molecular weight reduced to polystyrene of 1,000-20,000, preferably 1,500-10,000, and more preferably 2,000-5,000, measured using gel permeation chromatography. The molecular weight of this range is preferable to improve the characteristics of the resin composition, such as the viscosity of the resin composition, the period of time required for photo-fabrication, and the toughness of the cured product.

[0037] Examples of epoxy compounds suitable for the present invention are (1) epoxidated compounds obtained by a process which comprises epoxidating a double bond between carbons of a corresponding compound having an ethylenically unsaturated bond using an appropriate oxidizing agent such as hydrogen peroxide or peroxy acid process (1); (2) polymers having an epoxy group prepared by a process which comprises polymerizing a radically polymerizable monomer containing an epoxy group in a molecule process (2); and (3) compounds having an epoxy group prepared by a known process, e.g. a process comprising reacting a compound having a functional group, e.g. hydroxyl group, with epichlorohydrin process (3).

[0038] In order to prepare compounds having an epoxy group preferably used as component(B), which have a number average molecular weight reduced to polystyrene of 1,000-20,000, a compound having a number average molecular weight of 1,000-20,000 may be used as the raw material compound having an ethylenically unsaturated bond when using the above process (1). When using the process (2), a known method may be used to prepare a polymer with a desired polymerization degree. Also, when using the process (3), a compound having a number average molecular weight reduced to polystyrene of 1,000-20,000 may be used as the raw material compound having a functional group, e.g. hydroxyl group.

[0039] Given as typical examples of the epoxidated compounds of above-mentioned (1) are polymers of conjugated diene monomers, copolymers of conjugated diene monomers and compounds having an ethylenically unsaturated bond, copolymers of diene monomers and compounds having an ethylenically unsaturated bond, and compounds prepared by epoxidating a copolymer such as natural rubber. More particularly, examples of these compounds are

compounds produced by epoxidating a polymer of conjugated diene monomers such as a butadiene monomer or isoprene monomer; compounds prepared by epoxidating a copolymer of a conjugated diene monomer and a compound having an ethylenically unsaturated bond, e.g. ethylene, propylene, butene, isobutylene, styrene; compounds prepared by epoxidating a copolymer of a compound having an ethylenically unsaturated bond and a diene monomer, e.g. dicyclopentadiene; and compounds prepared by epoxidating a double bond contained in the molecule of rubber and the like. Commercially available epoxidated polybutadiene products include Poly bd R-45 EPI (manufactured by Idemitsu Petrochemical Co., Ltd.), R-15EPI, R-45EPI (manufactured by Nagase Chemicals Ltd.), and Epolead PB3600, PB4700 (manufactured by Daicel Chemical Industries Ltd.).

[0040] Given as examples of commercially available products of epoxidated compounds of a butadiene-styrene copolymer are Epofriend ESBS AT014, AT015, AT000 (manufactured by Daicel Chemical Industries Ltd.).

[0041] Given as examples of the polymer of the above-mentioned process (2) having an epoxy group are homopolymers produced from monomers such as glycidyl (meth)acrylate, vinylcyclohexene oxide, 4-vinylepoxycyclohexane, 3,4-epoxycyclohexylmethyl (meth)acrylate, or caprolactone modified 3,4-epoxycyclohexylmethyl (meth)acrylate, and copolymers of these monomers and other vinyl monomers. The number average molecular weight of these compounds is in the range of 1,000-20,000 as converted into polystyrene.

[0042] Given as examples of the compounds of the above-mentioned process (3) having an epoxy group prepared by the reaction of a compound having a functional group such as a hydroxyl group and epichlorohydrin are compounds prepared by the reaction of polybutadiene having hydroxyl groups at both terminals and epichlorohydrin.

[0043] Given as examples of commercially available products of the compounds of the above-mentioned process (3) are Poly bd R-45 EPT (manufactured by Idemitsu Petrochemical Co., Ltd.), and R-15EPT, R-45EPT (manufactured by Nagase Chemicals Ltd.). The number average molecular weight reduced to polystyrene of these compounds is in the range of 1,000-20,000. Among these examples of the compounds having an epoxy group, Poly bd R-45 EPI, R-15 EPI, R-45 EPI, and Epolead PB3600, PB4700 are preferable for use as component (B).

[0044] The above epoxy compounds may be used as component (B) either individually or in combinations of two or more.

[0045] The proportion of component (B) in the resin composition of the present invention is usually 3-50% by weight, preferably 4-40% by weight, and more preferably 5-30% by weight. If the proportion of component (B) is too low, the rate (curing rate) of the cationic polymerization reaction is so reduced that molding time may be extended and the resolution and toughness of the cured product may tend to be reduced. On the other hand, if the proportion of component (B) is too high, the viscosity the resin composition is increased and molding time may tend to be prolonged.

(C) Cationic photo-initiator

[0046] The cationic photo-initiator (hereinafter may be called from time to time component (C)) contained in the resin composition of the present invention is a compound capable of generating a molecule initiating cationic polymerization of components (A) and (B) upon exposure to radiation such as light.

[0047] Given as especially preferred examples of the cationic photo-initiator are onium salts represented by the following formula (17), which are compounds releasing Lewis acid on exposure to light:



wherein the cation is an onium ion; W represents S, Se, Te, P, As, Sb, Bi, O, I, Br, Cl, or N≡N; R¹², R¹³, R¹⁴, and R¹⁵ represent individually the same or different organic group; a, b, c, and d independently represent an integer from 0 to 3, and provided that a+b+c+d is equal to the valence number of W. M represents a metal or metalloid which constitutes a center atom of a halide complex. Typical examples of M are B, P, As, Sb, Fe, Sn, Bi, Al, Ca, In, Ti, Zn, Sc, V, Cr, Mn, and Co. X represents a halogen atom such as a fluorine atom, chlorine atom, or bromine atom. m is a substantial electric charge of the halide complex ion and n is the valence of M.

[0048] Given as typical examples of the onium salts represented by the formula (17) are diphenyliodonium, 4-methoxydiphenyliodonium, bis(4-methylphenyl)iodonium, bis(4-tert-butylphenyl)iodonium, bis(dodecylphenyl)-iodonium, triphenylsulfonium, diphenyl-4-thiophenoxy-phenylsulfonium, bis[4-(diphenylsulfonio)-phenyl]-sulfide, bis[4-(di(4-(2-hydroxyethyl)phenyl)sulfonio)-phenyl] sulfide, and η⁵-2,4-(cyclopentadienyl)-[(1,2,3,4,5,6-η)-(methylene)-benzene]-iron(1+).

[0049] Given as specific examples of the negative ion (MX_{n+m}) in the above formula (17) are tetrafluoroborate (BF₄⁻), hexafluorophosphate (PF₆⁻), hexafluoroantimonate (SbF₆⁻), hexafluoroarsenate (AsF₆⁻), and hexachloroantimonate (SbCl₆⁻).

[0050] Also, onium salts represented by the general formula [MX_n(OH)] (wherein M, X, and n are the same as defined

in formula (17)) can be used instead of those represented by the formula $[MX_{n+m}]$. Further, onium salts including a negative ion, for example, perchloric acid ion (ClO_4^-), trifluoromethane sulfonate ion ($CF_3SO_3^-$), fluorosulfonate ion (FSO_3^-), toluene sulfonate ion, trinitrobenzene sulfonate negative ion, and trinitrotoluene sulfonate ion, are given as other examples of onium salts.

[0051] Further, aromatic onium salts can be used as the cationic photo-initiator (C). Among these aromatic onium salts, the following compounds are preferred: aromatic halonium salts described, for example, in Japanese Patent Applications Laid-open No. 151996/1975 and No. 158680/1975; VIA group aromatic onium salts described, for example, in Japanese Patent Applications Laid-open No. 151997/1975, 30899/1977, No. 55420/1981, and No. 125105/1980; VA group aromatic onium salts described, for example, in Japanese Patent Application Laid-open No. 158698/1975; oxosulfoxonium salts described, for example, in Japanese Patent Applications Laid-open No. 8428/1981, No. 149402/1981, and No. 192429/1982; aromatic diazonium salts described, for example, in Japanese Patent Application Laid-open No. 17040/1974; and thiopyrylium salts described in the specification of USP No. 4,139,655. Iron/allene complex and aluminium complex/photo-decomposable silica compound initiators are also given as examples of the onium salts.

[0052] Preferred examples of commercially available products of the cationic photo-initiator which can be used as component (B) are UVI-6950, UVI-6970(bis[4-(di(2-hydroxyethyl)phenyl)sulfonio]-phenyl)sulfide), UVI-6974 (bis[4-(diphenylsulfonio)-phenyl]sulfidebis(hexafluoro-antimonate), UVI-6990 (hexafluorophosphate salt of UVI-6974) (manufactured by Union Carbide Corp), Adekaoptomer SP-151, SP-170 (bis[4-(di(4-(2-hydroxyethyl)phenyl)sulfonio]-phenyl)sulfide), SP-171 (manufactured by Asahi Denka Kogyo Co., Ltd.), Irgacure 261 (η^5 -2,4-(cyclopentadien-1-yl)-[1,2,3,4,5,6- η)-(1-methylethyl)benzene]-iron(1+)-hexafluorophosphate(1-)) (manufactured by Ciba Geigy), CI-2481, CI-2624, CI-2639, CI-2064 (manufactured by Nippon Soda Co., Ltd.), CD-1010, CD-1011, CD-1012 (4-(2-hydroxytetradecanyloxy)-diphenyliodonium hexafluoroantimonate (manufactured by Sartomer Co., Ltd.), DTS-102, DTS-103, NAT-103, NDS-103 ((4-hydroxynaphthyl)-dimethylsulfonium hexafluoroantimonate), TPS-102 (triphenylsulfonium hexafluoroantimonate), TPS-103 (triphenylsulfonium hexafluoroantimonate), MDS-103 (4-methoxyphenyl-diphenylsulfonium hexafluoroantimonate), MPI-103 (4-methoxyphenyliodonium hexafluoroantimonate), BBI-101 (bis(4-tert-butylphenyl)iodonium tetrafluoroborate), BBI-102 (bis(4-tert-butylphenyl)iodonium hexafluorophosphate), BBI-103 (bis(4-tert-phenyl)iodonium hexafluoroantimonate), (manufactured by Midori Chemical Co., Ltd.), and Degacure K126 (bis[4-(diphenylsulfonio)-phenyl] sulfide bis(hexafluorophosphate) (manufactured by Degussa Ltd.). Among these, UVI-6970, UVI-6974, Adekaoptomer SP-170, SP-171, CD-1012, MPI-103 are particularly preferred.

[0053] The above-mentioned cationic photo-initiators can be used as component (C) either individually or in combinations of two or more.

[0054] The proportion of component (C) in the resin composition of the present invention is 0.1-10% by weight, preferably 0.2-5% by weight, and more preferably 0.3-3% by weight. If the proportion of component (C) is too low, the photo-curing characteristic of the resin composition obtained is insufficient. It becomes difficult to form a three-dimensional object having sufficient mechanical strength from such a resin composition. Similarly, if the proportion of component (C) is too high, it becomes difficult to obtain the appropriate light capability (curing depth) when the resulting resin composition is used in the photo-fabrication process. In addition, the mechanical strength such as toughness of the three-dimensional object prepared from such a resin composition tends to be reduced.

Optional components

[0055] In addition to the above essential components (A) to (C), other components may be incorporated into the photo-curable resin composition of the present invention as required to the extent that the effects of this invention are not adversely affected. For example, cationically polymerizable organic compounds other than components (A) and (B) may be given. A cationically polymerizable compound is defined as a compound having an organic group which can polymerize or crosslink by photo-irradiation in the presence of an acid or a cation. Such cationically polymerizable organic compounds include epoxy compounds other than component (B), oxolane compounds, cyclic acetal compounds, cyclic lactone compounds, thiirane compounds, thietane compounds, vinyl ether compounds, spiro-ortho ester compounds which are reaction products of an epoxy compound and lactone, ethylenically unsaturated compounds, cyclic ether compounds, cyclic thioether compounds, and vinyl compounds.

[0056] Examples of epoxy compounds other than component (B) are in particular, epoxy compounds with a molecular weight of less than about 1000 which include alicyclic epoxy compounds such as

3,4-epoxycyclohexylmethyl-3',4'-epoxy-cyclohexane carboxylate,
2-(3,4-epoxycyclohexyl-5,5-spiro-3,4-epoxy)cyclohexane-metha-dioxane, bis(3,4-epoxy-cyclohexylmethyl)adipate, vinylcyclohexene oxide, 4-vinyl epoxycyclohexane, bis(3,4-epoxy-6-methylcyclohexylmethyl) adipate, 3,4-epoxy-6-methylcyclohexyl-3',4'-epoxy-6'-methyl-cyclohexane carboxylate, methylenebis(3,4-epoxy-cyclohexane), dicyclopenta-

diene diepoxide, di(3,4-epoxy-cyclohexylmethyl) ether of ethylene glycol, ethylene-bis(3,4-epoxycyclohexanecarboxylate), epoxidated tetrabenzyl alcohol, lactone modified epoxidated tetrahydrobenzyl alcohol, cyclohexene oxide, bisphenol A diglycidyl ether, bisphenol F diglycidyl ether, bisphenol S diglycidyl ether, bisphenol A diglycidyl ether, bisphenol F diglycidyl ether, bisphenol S diglycidyl ether, hydrogenated bisphenol A diglycidyl ether, hydrogenated bisphenol F diglycidyl ether, hydrogenated bisphenol AD diglycidyl ether, brominated bisphenol A diglycidyl ether, brominated bisphenol F diglycidyl ether, brominated bisphenol S diglycidyl ether, an epoxy novolac resin, 1,4-butanediol diglycidyl ether, 1,6-hexanediol diglycidyl ether, glycerol triglycidyl ether, trimethylolpropane triglycidyl ether, polyethylene glycol diglycidyl ether, polypropylene glycol diglycidyl ethers; polyglycidyl ethers of polyether polyol obtained by adding one or more alkylene oxide to aliphatic polyhydric alcohol such as ethylene glycol, propylene glycol, or glycerol; diglycidyl esters of aliphatic long chain dibasic acid; monoglycidyl ethers of aliphatic higher alcohol; monoglycidyl ethers of phenol, cresol, butyl phenol, or polyether alcohol obtained by addition of alkylene oxide to phenol, cresol, or butyl phenol; glycidyl esters of higher fatty acid; epoxidated soybean oil, butyl epoxystearate, octyl epoxystearate, epoxidated polybutadiene, and epoxidated linseed oil.

[0057] Other cationically polymerizable compounds which can be additionally used are oxolane compounds such as tetrahydrofuran and 2,3-dimethyltetrahydrofuran; cyclic acetals such as trioxane, 1,3-dioxolane, and 1,3,6-trioxane cyclooctane; cyclic lactones such as β -propiolactone and ϵ -caprolactone; thiiranes such as ethylene sulfide, 1,2-propylene sulfide, and thioepychlorohydrin; thiethanes such as 3,3-dimethyl thiethane; vinyl ethers such as ethylene glycol divinyl ether, triethylene glycol divinyl ether, and trimethylolpropane trivinyl ether; spiro-ortho esters which are obtained by a reaction of epoxy compound and lactone; ethylenically unsaturated compounds such as vinyl cyclohexane, isobutylene, and polybutadiene; and their derivatives.

[0058] The resin composition of the present invention may contain polyols for developing photo-curability of the resin composition, and the shape stability (resistance to deformation with time) and characteristic stability (resistance to change in mechanical performance with time) of the three-dimensional object obtained from the resin composition. The polyether polyol has three or more, preferably from 3 to 6 hydroxyl groups in one molecule. If polyether polyols (polyether diols) having less than three hydroxyl groups are used, the object of developing the photo-curing characteristics can not be achieved and a three-dimensional object with sufficient mechanical strength can not be produced. On the other hand, if polyether polyols having 7 or more hydroxyl groups are used, the elongation and toughness of the three-dimensional object obtained from the resin composition tends to be lower.

[0059] Specific examples of suitable polyols are polyether polyols prepared by modifying polyhydric alcohol of more than 3 valences such as for example trimethylolpropane, glycerol, pentaerythritol, sorbitol, sucrose, quodolol, by a cyclic ether compound such as for example ethylene oxide (EO), propylene oxide, tetrahydrofuran; caprolactone polyols prepared by modifying caprolactone; and polyester polyols prepared by modifying polyesters consisting of a dibasic acid and a diol. Specific examples of such polyether polyols are EO modified trimethylolpropane, PO modified trimethylolpropane, tetrahydrofuran modified trimethylolpropane, caprolactone modified trimethylolpropane, EO modified glycerol, PO modified glycerol, tetrahydrofuran modified glycerol, caprolactone modified glycerol, EO modified pentaerythritol, PO modified pentaerythritol, tetrahydrofuran modified pentaerythritol, caprolactone modified pentaerythritol, EO modified sorbitol, PO modified sorbitol, caprolactone modified sorbitol, EO modified sucrose, PO modified sucrose, and EO modified quodol. Among these, EO modified trimethylolpropane, PO modified trimethylolpropane, caprolactone modified trimethylolpropane, PO modified glycerol, caprolactone modified glycerol, and PO modified sorbitol are preferred.

[0060] Specific examples of commercially available products (polyols) are Sunnix TP-400, Sunnix GP-600, Sunnix GP-1000, Sunnix SP-750, Sunnix GP-250, Sunnix GP-400, Sunnix GP-600 (manufactured by Sanyo Chemical Industries, Ltd.), TMP-3 Glycol, PNT-4 Glycol, EDA-P-4, EDA-P-8 (manufactured by Nippon Nyukazai Co., Ltd.), G-300, G-400, G-700, T-400, EDP-450, SP-600, SC-800 (manufactured by Asahi Denka Kogyo Co., Ltd.), TONE 0301, TONE 0305, TONE 0310 (manufactured by Union Carbide Corp.), and PLACCEL 303, PLACCEL 305, PLACCEL 308 (manufactured by Daicel Chemical Industries, Ltd.).

[0061] The resin composition of the present invention may include an ethylenically unsaturated monomer, which is a radically polymerizable compound, to improve the mechanical strength of the cured product and to reduce the time required for fabrication. The ethylenically unsaturated monomer is a compound having ethylenically unsaturated groups (C=C) in the molecule. Given as typical examples of component (C) are mono-functional monomers having one ethylenically unsaturated bond in one molecule, and polyfunctional monomers having two or more ethylenically unsaturated bonds in one molecule.

[0062] Examples of mono-functional monomers are acrylamide, (meth)acryloyl morpholine, 7-amino-3,7-dimethyloctyl (meth)acrylate, isobutoxymethyl (meth)acrylamide, isobornyl (meth)acrylate, isobornyl (meth)acrylate, 2-ethylhexyl (meth)acrylate, ethyldiethylene glycol (meth)acrylate, t-octyl (meth)acrylamide, diacetone (meth)acrylamide, dimethylaminoethyl (meth)acrylate, diethylaminoethyl (meth)acrylate, lauryl (meth)acrylate, dicyclopentadiene (meth)acrylate, dicyclopentenyl (meth)acrylate, dicyclopentenyl (meth)acrylate, N,N-dimethyl (meth)acryla-

midate tetrachlorophenyl (meth)acrylate, 2-tetrachlorophenoxyethyl (meth)acrylate, tetrahydrofurfuryl (meth)acrylate, tetrabromophenyl (meth)acrylate, 2-tetrabromophenoxyethyl (meth)acrylate, 2-trichlorophenoxyethyl (meth)acrylate, tribromophenyl (meth)acrylate, 2-tribromophenoxyethyl (meth)acrylate, 2-hydroxyethyl (meth)acrylate, 2-hydroxypropyl (meth)acrylate, vinyl caprolactam, N-vinyl pyrrolidone, phenoxyethyl (meth)acrylate, butoxyethyl (meth)acrylate, pentachlorophenyl (meth)acrylate, pentabromophenyl (meth)acrylate, polyethylene glycol mono-(meth)acrylate, polypropylene glycol mono-(meth)acrylate, bornyl (meth)acrylate, methyltriethylene diglycol (meth)acrylate, alkoxylated alkyl phenol acrylate, the (poly)caprolactone acrylate ester from methylol-tetrahydrofuran and the (poly)caprolactone acrylate ester from alkylol-dioxane. These compounds may be used either individually or in combinations of two or more.

[0063] Among these monofunctional monomers, isobornyl (meth)acrylate, lauryl (meth)acrylate, and phenoxyethyl (meth)acrylate are particularly preferred.

[0064] Examples of commercially available products of monofunctional monomers are Aronix M-101, M-102, M-111, M-113, M-117, M-152, TO-1210 (manufactured by Toagosei Chemical Industry Co., Ltd.), KAYARAD TC-110S, R-564, R-128H (manufactured by Nippon Kayaku Co., Ltd.), and Viscoat 192, Viscoat 220, Viscoat 2311HP, Viscoat 2000, Viscoat 2100, Viscoat 2150, Viscoat 8F, Viscoat 17F (manufactured by Osaka Organic Chemical Industry Co., Ltd.)

[0065] Preferred examples of polyfunctional monomers are ethylene glycol di(meth)acrylate, dicyclopentenyl di(meth)acrylate, triethylene glycol diacrylate, tetra ethylene glycol di(meth)acrylate, tricyclodecanediyl-dimethylene di(meth)acrylate, tris(2-hydroxyethyl) isocyanurate di(meth)acrylate, tris(2-hydroxyethyl) isocyanurate tri(meth)acrylate, caprolactone modified tris(2-hydroxyethyl) isocyanurate tri(meth)acrylate, trimethylolpropane tri(meth)acrylate, EO modified trimethylolpropane tri(meth)acrylate, PO modified trimethylolpropane tri(meth)acrylate, tripropylene glycol di(meth)acrylate, neopentyl glycol di(meth)acrylate, both terminal (meth)acrylic acid adduct of bisphenol A diglycidyl ether, 1,4-butanediol di(meth)acrylate, 1,6-hexanediol di(meth)acrylate, pentaerythritol tri(meth)acrylate, pentaerythritol tetra(meth)acrylate, polyester di(meth)acrylate, polyethylene glycol di(meth)acrylate, dipentaerythritol hexa(meth)acrylate, dipentaerythritol penta(meth)acrylate, dipentaerythritol tetra(meth)acrylate, caprolactone modified dipentaerythritol hexa(meth)acrylate, caprolactone modified dipentaerythritol penta(meth)acrylate, ditrimethylolpropane tetra(meth)acrylate, EO modified bisphenol A di(meth)acrylate, PO modified bisphenol A di(meth)acrylate, EO modified hydrogenated bisphenol A di(meth)acrylate, PO modified hydrogenated bisphenol A di(meth)acrylate, EO modified bisphenol F di(meth)acrylate, and phenol novolac polyglycidyl ether. These compounds may be used either individually or in combinations of two or more.

[0066] These polyfunctional monomers can be selected from the above-mentioned tri(meth)acrylate compounds, tetra(meth)acrylate compounds, penta(meth)acrylate compounds, and hexa(meth)acrylate compounds. Among these, preferred polyfunctional monomers are trimethylolpropane tri(meth)acrylate, EO modified trimethylolpropane tri(meth)acrylate, PO modified trimethylolpropane tri(meth)acrylate, pentaerythritol tri(meth)acrylate, pentaerythritol tetra(meth)acrylate, dipentaerythritol hexa(meth)acrylate, dipentaerythritol penta(meth)acrylate, dipentaerythritol tetra(meth)acrylate, caprolactone modified dipentaerythritol hexa(meth)acrylate, caprolactone modified dipentaerythritol penta(meth)acrylate, and ditrimethylolpropane tetra(meth)acrylate. However, the present invention is not limited to these examples.

[0067] Given as commercially available products of these polyfunctional monomers are SA1002 (manufactured by Mitsubishi Chemical Corp.), Viscoat 195, Viscoat 230, Viscoat 260, Viscoat 215, Viscoat 310, Viscoat 214HP, Viscoat 295, Viscoat 300, Viscoat 360, Viscoat GPT, Viscoat 400, Viscoat 700, Viscoat 540, Viscoat 3000, Viscoat 3700 (manufactured by Osaka Organic Chemical Industry Co., Ltd.), KAYARAD R-526, HDDA, NPGDA, TPGDA, MANDA, R-551, R-712, R-604, R-684, PET-30, GPO-303, TMPTA, THE-330, DPHA, DPHA-2H, DPHA-2C, DPHA-2I, D-310, D-330, DPCA-20, DPCA-30, DPCA-60, DPCA-120, DN-0075, DN-2475, T-1420, T-2020, T-2040, TPA-320, TPA-330, RP-1040, RP-2040, R-011, R-300, R-205 (manufactured by Nippon Kayaku Co., Ltd.), Aronix M-210, M-220, M-233, M-240, M-215, M-305, M-309, M-310, M-315, M-325, M-400, M-6200, M-6400 (manufactured by Toagosei Chemical Industry Co., Ltd.), Light acrylate BP-4EA, BP-4PA, BP-2EA, BP-2PA, DCP-A (manufactured by Kyoeisha Chemical Industry Co., Ltd.), New Frontier BPE-4, TEICA, BR-42M, GX-8345 (manufactured by Daiichi Kogyo Seiyaku Co., Ltd.), ASF-400 (manufactured by Nippon Steel Chemical Co., Ltd.), Ripoxy SP-1506, SP-1507, SP-1509, VR-77, SP-4010, SP-4060 (manufactured by Showa Highpolymer Co., Ltd.), and NK Ester A-BPE-4 (manufactured by Shin-Nakamura Chemical Industry Co., Ltd.).

[0068] When compounding an ethylenically unsaturated monomer into a resin composition, a radical photo-initiator is usually added to the resin composition to initiate the radical polymerization reaction of the ethylenically unsaturated monomer. The radical photo-initiator is a compound which decomposes and generates radicals by photo-irradiation and initiates a radical reaction of the ethylenically unsaturated monomer by generating free radicals. Conventionally known radical photo-initiators may be used in the present invention.

[0069] Specific examples of radical photo-initiators are acetophenone, acetophenone benzyl ketal, anthraquinone, 1-(4-isopropylphenyl)-2-hydroxy-2-methylpropan-1-one, carbazole, xanthone, 4-chlorobenzo-phenone, 4,4'-diaminobenzophenone, 1,1-dimethoxydeoxybenzoin, 3,3'-dimethyl-4-methoxybenzophenone, thioxanethone compounds, 2-methyl-1-4-(methylthio) phenyl-2-morpholino-propane-2-on, 2-benzyl-2-dimethylamino-1-(4-morpholinophenyl)-butan-1 one, triphenylamine, 2,4,6-trimethylbenzoyl diphenylphosphine oxides, bis (2, 6-dimethoxybenzoyl) -2,4,4-tri-

methylpentyl-phosphine oxide, benzyl dimethyl ketal, 1-hydroxycyclohexyl phenyl ketone, 2-hydroxy-2-methyl-1-phenylpropane-1-one, fluorenone, fluorene, benzaldehyde, benzoin ethyl ether, benzoin propyl ether, benzophenone, Michler's ketone, 3-methylacetophenone, 3,3', 4,4'-tetra (t-butyl peroxy carbonyl) benzophenone (BTTB), and combined compositions of BTTB and xanthene, thioxanthene, coumarin, ketocoumarin or other coloring matter photosensitizer.

5 Among these, benzyl dimethyl ketal, 1-hydroxycyclohexyl phenyl ketone, 2,4,6-trimethylbenzoyl diphenylphosphine oxide, 2-benzyl-2-dimethylamino-1-(4-morpholinophenyl)-butan-1-one, and the like are particularly preferred.

[0070] Additives other than the cationically polymerizable compound and the radical photo-initiator, which may be employed in the resin composition as required, are photosensitizers (polymerization promoters) of amine compounds such as triethanolamine, methyl diethanolamine, triethylamine, diethylamine; photosensitizers including thioxanthone

10 or its derivatives, anthraquinone or its derivatives, anthracene or its derivatives, perillene and its derivatives, benzophenone, benzoin isopropylether, and the like; and reaction diluents such as vinyl ether, vinyl sulfide, vinyl urethane, or vinyl urea.

[0071] Other additives include polymers or oligomers, such as epoxy resins other than the above-mentioned compound having an epoxy group used as component (B) and other epoxy compounds, polyamide, polyamideimide, polyurethane, polybutadiene, polychloroprene, polyether, polyester, styrene-butadiene-styrene block copolymer, petroleum resin, xylene resin, ketone resin, cellulose resin, fluorine oligomer, silicon oligomer, and polysulfide oligomer; polymerization inhibitors such as phenothiazine or 2,6-di-t-butyl-4-methyl phenol, polymerization initiation adjuvants, age resisters, leveling agents, wettability improvers, surfactants, plasticizers, UV stabilizers, UV absorbers, silane coupling agents, pigments and dyes. Also, the resin composition of the present invention may include inorganic fillers, organic

20 fillers. Specific examples of the above inorganic fillers are solid microparticles of inorganic compounds, such as glass beads, talc microparticles, and silicon oxide, and whiskers of basic magnesium sulfonate, aluminum oxide, or silicon oxide. Specific examples of the above organic fillers are organic solid microparticles of crosslinked polystyrene high polymer, crosslinked polymethacrylate high polymer, crosslinked polyethylene high polymer, and crosslinked polypropylene high polymer. Also, products from such inorganic fillers or organic fillers treated with a silane coupling agent

25 such as aminosilane, epoxysilane, and acrylsilane can be utilized.

[0072] Typically, compositions of the present invention will have a dimensional accuracy value of less than 0.15, preferably less than 0.12, more preferably less than 0.10 mm (reference dimensional accuracy test procedure, below).

[0073] The curability of the resin compositions of the present invention, as measured by the difference in Young's modulus at different curing doses is substantially the same. The resin composition preferably is formulated to have a

30 Young's modulus after curing of a film, of 80 kg/mm² or higher, preferably 100 kg/mm² or higher. Generally, the Young's modulus of a cured film will be about 400 kg/mm² or less. Typically, this Young's modulus is substantially the same when exposed to an irradiation dose of 100 and 500 mJ/cm², which means that the difference between the two Young's modulus is less than 20%, more preferably less than 10% of the highest value measured. When the resin composition is cured at 100 mJ/cm² and 500 mJ/cm², the difference in Young's modulus is typically less than 25,

35 preferably less than 10, and more preferably is 4 kg/mm² or less (reference test procedure, below).

[0074] The tensile elongation of the cured film preferably is between about 10-40%, more preferably, between about 13-30%.

Preparation of Resin composition

40

[0075] The resin composition of the present invention can be manufactured by homogeneously blending the above-mentioned components (A) to (C), the optional components which are added as required, and the various additives.

[0076] The resulting resin compositions are useful for photocurable resin compositions for photo-fabrication. It is desirable for the photo-curable resin composition of the present invention to possess a viscosity at 25°C in the range

45 of 50-10,000 cps, preferably 100-5,000 cps.

Photo-fabricating process

[0077] The photo-curable resin composition of the present invention prepared in the manner discussed herein is suitable as a photo-curable (liquid) material used in photo-fabrication processes. Specifically, a three-dimensional object with a desired shape can be obtained by using the photo-fabrication process, including selectively irradiating visible light, ultraviolet light, or infrared light on the photo-curable resin composition of the present invention, and feeding the energy required to cure the resin composition.

50

[0078] Various means may be used to selectively irradiate the photo-curable resin composition with light with no specific limitations. Such light irradiation means include, for example, a laser beam, a means for irradiating the composition with light converged by a lens, mirror, or the like, while scanning, a means irradiating the composition with non-convergent light through a mask provided with a fixed pattern through which light is transmitted, and a means for irradiating the composition with light via a number of optical fibers bundled in a light conductive member corresponding

55

to a fixed pattern. In the means using a mask, a mask electrooptically produces a mask image consisting of a light transmitting area and non-light-transmitting area according to a prescribed pattern by the same theory as that of the liquid crystal display apparatus. A means using a scanning laser beam with a small spot size is preferred for selectively irradiating the resin composition with light, when a resulting three-dimensional object possesses minute parts or when high dimensional accuracy is required to form the three-dimensional object.

[0079] In the above means, the irradiated surface (for example, a plane scanned by light) of the resin composition placed in a vessel is either the liquid surface of the resin composition or the interface of the liquid and a translucent wall of the vessel. When the irradiated surface is the liquid surface or the interface of the liquid and the wall of the vessel, the light can be shone directly out of the vessel or through the vessel.

[0080] In the above photo-fabrication process, a desired solid shape can be made by curing fixed parts of the resin composition and then moving the light spot from the cured parts to the uncured parts continuously or stepwise to laminate the cured parts. There are various methods for moving the light spot, for example, a method for moving any of the light source, the vessel for the resin composition, or the cured parts of the resin composition. Also there is a method in which a fresh resin composition is supplied to the cured resin composition in the vessel.

[0081] Illustrating a typical photo-fabrication process, the surface of a support stage capable of being optionally elevated in the vessel is slightly lowered from the liquid surface to form a thin layer (1) of the resin composition. The thin layer (1) is selectively irradiated with light to form a solid cured resin layer (1'). The resin composition is supplied over this thin layer (1') to form a second thin layer (2), and this thin layer (2) is selectively irradiated with light to laminate a new solid cured resin layer (2') on the thin layer (1'). This step is repeated for a prescribed number of times, with or without changing the pattern subjected to light irradiation, to produce a three-dimensional object consisting of a multiple number of cured resin layers (1') to (n') which are integrally laminated.

[0082] The three-dimensional object fabricated in this manner is discharged from the vessel and processed to remove the unreacted photo-curable resin composition remaining on the surface, and washed by a solvent, as required. Given as examples of solvents are an organic solvent which is represented by an alcohol, such as isopropyl alcohol or ethyl alcohol, an organic solvent such as acetone, ethyl acetate, methylethyl ketone, an aliphatic organic solvent such as a terpene, or a low viscosity liquid thermosetting resin or photo-curable resin.

[0083] When forming a three-dimensional object with a smooth surface, it is desirable that the cured product be washed using the thermosetting resin or photo-curable resin. In this case, it is necessary to post-cure the product by heat emission or light irradiation depending on the type of solvent used in the washing stage. This post-curing treatment is effective not only for curing the resin remaining uncured on the surface of the laminated body, but also for curing the resin composition which remains uncured inside the laminated body. Thus, the post-curing treatment is also effective in the case where the fabricated three-dimensional object is washed with an organic solvent.

[0084] The three-dimensional object obtained in this manner has high mechanical strength, high dimensional accuracy, and excellent heat resistance. Also, the three-dimensional object exhibits high stability in maintaining a fixed shape and lasting stable properties. Therefore, the three-dimensional object prepared from the resin composition is preferably used for trial mechanical parts for confirming the functions.

[0085] It is desirable to cover the surface of the three-dimensional object by a heat-curable or photo-curable hard coating agent to improve the strength and heat resistance of the surface. As such for example a hard coating agent, an organic coating agent such as acrylic resin, epoxy resin, silicone resin or an inorganic coating agent can be used. These hard coating agents may be used individually or in combinations of two or more.

EXAMPLES

[0086] The present invention will be explained in more detail by way of examples, which are not intended to be limiting of the present invention.

Example 1

[0087] According to the formulation shown in Table 1, 90 parts by weight of (1,4-bis[(3-ethyl-3-oxetanylmethoxy)methyl]- benzene as component (A), 9 parts by weight of Epolead PB3600 (epoxydated polybutadiene) as component (B), and 1 part by weight of UVI-6974 (manufactured by Union Carbide Corp.), as component (C), were placed in a vessel equipped with a stirrer and the mixture was reacted with stirring at 60°C for one hour to prepare a transparent liquid composition.

Examples 2-5

[0088] Transparent liquid compositions were prepared in the same manner as in Example 1 according to the formulations shown in Table 1, except that the different components were used.

Comparative Examples 1-5

[0089] Transparent liquid compositions (comparative resin compositions) were prepared in the same manner as in Example 1 according to the formulations shown in Table 1, except that the different components and optional components were used. These comparative resin compositions had the following characteristics.

Comparative Example 1: component (B) was not used.

Comparative Example 2: 3,4-Epoxy cyclohexylmethyl-3',4'-epoxyhexane carboxylate was used instead of component (A).

Comparative Example 3: component (B) was not used.

Comparative Example 4: An epoxy/acryl monomer hybrid-type photocurable resin composition.

Comparative Example 5: Urethane acrylate photocurable resin composition.

a. Synthesis of urethane acrylate

[0090] 3,311 g of isophorone diisocyanate, 10 g of dibutyltin dilaurate, and 3 g of 2,6-di(tert)-butyl-4-methylphenol as a polymerization inhibitor were placed in a reaction vessel equipped with a stirrer. Next, 1,730 g of hydroxyethyl-acrylate was added to the mixture while controlling the temperature at less than 20°C. After the addition, the resulting mixture was further agitated for one hour. 7,458 g of polyester diol (trade mark: P-1010, manufactured by Kuraray Co., Ltd.) which was consisting of 3-methyl-1,5-pentane diol and adipic acid and which has a number average molecular weight of 1,000 was then added to the mixture, keeping the temperature at 40-50°C. The reaction was terminated after the agitation was further continued for five hours at 50-60°C to obtain urethane acrylate (U-1) with a number average molecular weight of 1,680.

b. Preparation of liquid resin composition

[0091] 36 parts by weight of urethane acrylate (U-1), 18 parts by weight of tricyclodecanediyldimethylene diacrylate as a reaction diluent, 23 parts by weight of isobornyl acrylate, 16 parts by weight of acryloyl morpholine, and 7 parts by weight of 1-hydroxyphenyl ketone as a photo-initiator were agitated and mixed at 50-60°C to obtain a transparent liquid resin composition.

TABLE 1

	Example					Comparative Example				
	1	2	3	4	5	1	2	3	4	5
Component A 1,4-bis[(3-ethyl-3-oxetanylmethoxy)methyl]benzene	90	75	70	63	58	99		75		
Component B Epoxidated polybutadiene (Epolead PB3600)	9	24	9	21	18		24			
Component C UVI-6974	1	1	1	1	1	1	1	1	1	1
3,4-epoxycyclohexylmethyl-3',4'-epoxycyclohexane carboxylate			20				75	24	49	
1,4-butanediol diglycidyl ether									21	
Caprolactone modified trimethylolpropane					8				14	
Trimethylolpropane triacrylate				14	14				14	
1-hydroxyphenyl ketone				1	1				1	7
Urethane acrylate (U-1)										36
Tricyclodecanediyl dimethylene diacrylate										18
Isobornyl acrylate										23
Acryloyl morpholine										16

Evaluation of the resin composition

[0092] The photo-curable resin compositions prepared in Examples 1-5 and Comparative Examples 1-5 were evaluated by measuring the curability of the resin solution, the toughness of the cured film, and the fabricating capability of three-dimensional objects according to the following methods for evaluation. The results are shown in Table 2.

Curability of the resin solution

[0093] The curability of the resin solution shows a degree (curing rate) of polymerization reaction and crosslinking reaction of the resin composition with respect to the energy of photo-irradiation. The curing rate has influences on the dynamic properties of the cured products, such as Young's modulus, bending elasticity, and the like. Specifically, excellent photo-curability is thought to ensure minimal change in the dynamic properties of the cured product to be produced. In this invention, the curability of the resin solution is evaluated by measuring the Young's modulus of the cured resin film formed by irradiation of lights at different doses.

(1) Preparation of test specimens

[0094] A coated film with a thickness of 200 μm was prepared by applying a resin composition to a glass plate using an applicator. The surface of the film was irradiated with ultraviolet light at doses of 100 mJ/cm^2 and 500 mJ/cm^2 using a conveyer curing apparatus equipped with a metal halide lamp (UB0311-00 type, manufacture by Eye Graphics Co., Ltd.) to prepare a cured resin film. The cured resin film was allowed to stand in an air conditioned room maintained at 23°C and RH 50% for one hour to produce test specimens. These test specimens were subjected to measurement.

(2) Measurement of Young's modulus

[0095] The Young's modulus of the test specimens which had been treated at 23°C and RH 50% and cured by irradiation with different doses of light, as noted in Table 2, was measured under the conditions of a drawing rate of 1 mm/min and a bench mark distance of 25 mm using a tension tester (AUTOGRAPH AGS-IKDN, manufactured by Shimadzu Corporation). The results are shown in table 2.

Toughness of the cured film

[0096] The toughness of the cured product shows resistance to external stress. One indicia of the resins toughness is tensile elongation. In this invention, toughness of the cured film was evaluated by measuring the tensile elongation of the cured resin film.

(1) Preparation of test specimen

[0097] A coated film with a thickness of 200 μm was prepared by applying a resin composition to a glass plate using an applicator. The surface of the film was irradiated with ultraviolet light at a dose of 500 mJ/cm^2 using a conveyer curing apparatus equipped with a metal halide lamp. The irradiation was terminated before the resin composition was completely cured to prepare a half-cured resin film. Next, the half cured resin film was peeled from the glass plate and placed on releasable paper. The side opposite to that first cured by irradiation was irradiated with ultraviolet light at a dose of 500 mJ/cm^2 to prepare a completely cured resin film.

[0098] The cured resin film was allowed to stand in an air-conditioned room maintained at a temperature of 23°C and a humidity of 50% for 24 hours.

(2) Measurement of tensile elongation

[0099] The tensile elongation of the test specimen was measured at a temperature of 23°C under a humidity of 50% and the conditions of a drawing rate of 1 mm/min and a bench mark distance of 25 mm using the above tension tester. The results are shown in Table 2.

Fabricating capability of three-dimensional objects

[0100] The fabricating capability of the three-dimensional objects was evaluated by measuring the dimensional accuracy of the three-dimensional object prepared from each resin composition and time required for the fabrication.

(1) Fabrication of three-dimensional object

[0101] Using a photo-fabrication apparatus (Solid Creator SCS-1000HD, manufactured by Sony Corporation), the resin compositions prepared in the Examples 1-5 and Comparative Examples 1-5 were fabricated according to the following conditions to produce three-dimensional objects each having an H-shape configuration as shown in the Figure. With respect to the target dimension of the product, the two columns and the horizontal beam constituting the H shaped object 10 were all made of a prism with a 6.4 mm x 6.4 mm square cross section. The lengths of the columns 11 & 12 and horizontal beam 13 were 44.5 mm and 88.8 mm, respectively. Other target dimensions are shown in the Figure.

[0102] The fabricated three-dimensional object was allowed to stand in an air-conditioned room maintained at 23°C and RH 50% to condition.

1.a Fabricating conditions**[0103]**

- (i) Laser beam intensity on the liquid surface: 10 mW
- (ii) Scanning velocity: the optimum velocity for the cured depth of the composition to be 0.15 mm.
- (iii) Thickness of cured resin layer: 0.1 mm
- (iv) Number of lamination: 445

(2) Measurement of dimensional accuracy of the fabricated three-dimensional object

[0104] To determine the molding accuracy of the three-dimensional object 10 with the H-shape, the actual widths 14 and 16 at positions 14a and 16a were measured using calipers having a measuring accuracy of 0.01 mm to calculate the differences between the lengths 14 and 15, measured at 15a, and the lengths 16 and 15, similarly measured at 15a, according to the equations (I) and (II) illustrated below. The dimensional accuracy was evaluated based on these differences. The results are shown in Table 2.

$$\text{Dimensional difference between A and B} = (A - B) \quad (\text{I})$$

$$\text{Dimensional difference between C and B} = (C - B) \quad (\text{II})$$

(3) Measurement of the time required for fabrication

[0105] The time required for fabricating the three-dimensional object with the H-shape shown in the Figure 1 using the above photo-fabrication apparatus was measured. The results are shown in Table 2.

TABLE 2

		Example					Comparative Example				
		1	2	3	4	5	1	2	3	4	5
[Curability of resin solution] Young's modulus of cured film (kg/mm ²)	Irradiation dose	112	115	134	113	106	17	25	134	60	104
	100 mJ/cm ²										
	500 mJ/cm ²	115	119	137	116	107	42	63	137	132	104
[Toughness of cured product] Tensile elongation of cured film (%)		17	18	17	19	18	5	13	7	6	30
[Fabrication capability] Dimensional accuracy (mm)	Difference A-B	-0.10	-0.09	-0.09	-0.10	-0.09	-	-0.09	-0.15	-0.07	-0.32
	C-B	0.07	0.08	0.08	0.09	0.08	-	0.11	0.24	0.10	0.65
Time for fabrication (hour)		8.1	8.5	9.0	8.5	8.5	*	35	8.5	22	7.2

*: The Green strength of the fabricated product was so low that a target three-dimensional object could not be produced.

[0106] As clear from Table 2, difference in the Young's modulus of cured films prepared from the resin solutions containing the resin compositions of the Examples 1-5 was small when the resin compositions were cured by irradiation with lights at doses of 100 mJ/cm² and 500 mJ/cm², demonstrating show excellent curability of the resin composition of the present invention. Also, the Young's modulus of the cured films exceeded 100 kg/mm², indicating that the cured products from these resin compositions exhibit sufficient mechanical strength for photo-fabricating applications. On the other hand, the Young's modulus of the cured film of the resin composition prepared in the Comparative Example 1 excluding component (B) was so small that no sufficient curability and mechanical strength required for photo-fabricating applications were provided. The resin composition prepared in the Comparative Example 2 excluding component (A) exhibited only insufficient curability and mechanical strength because the Young's modulus of a cured film of the resin composition was small similarly to that obtained in the Comparative Example 1. The Young's modulus of the photocurable resin composition of the epoxy/acryl monomer hybrid type, which was prepared in the Example 4, was so low that the curability of the resin composition was insufficient for photo-fabricating applications.

[0107] The tensile elongation of the cured films prepared from the resin compositions of the Examples 1-5 ranged from 17% to 19%, indicating sufficient toughness for photo-fabricating applications. On the other hand, the tensile elongation of the resin compositions excluding component (B) which were prepared in the Comparative Examples 1 and 3 was 5% and 7% respectively. Therefore, the toughness of the resin compositions excluding component (B) was insufficient for photo-fabricating applications. In addition, the tensile elongation of the resin composition prepared in the Comparative Example 4 was 6% so that sufficient toughness for photo-fabricating applications could not be provided.

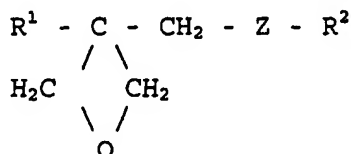
[0108] Illustrating the photo-fabricated products of the photocurable resin compositions used for photo-fabrication, which were prepared in the Examples and the Comparative Examples, the photocurable resin compositions prepared in the Examples 1-5 and the urethane acrylate type photocurable resin composition prepared in the comparative Example 5 required less than 10 hours to be optically molded. On the other hand, for the resin composition prepared in the Comparative Example 1, the strength of the resin cured by laser irradiation, which was called "Green strength", was so small that a target three-dimensional object could not be produced. Also, the resin compositions prepared in the Comparative Examples 2 and 4 required more than 20 hours to be optically molded.

[0109] Concerning the dimensional accuracy, excellent fabricated products with small dimensional differences could be produced from the resin compositions prepared in the Examples 1-5 and the Comparative Examples of 2 and 4. However, the fabricated products produced from the Comparative Examples 3 and 5 exhibited large dimensional differences so that sufficient dimensional accuracy required for photo-fabrication could not be obtained.

[0110] As clear from the above illustrations, the photocurable resin composition used for photo-fabrication in the present invention has excellent photocurability, by which the resin composition can be promptly cured by irradiation with lights so that the time required for fabrication can be reduced. Also, shrinkage during curing is so small, so that three-dimensional objects having high dimensional accuracy and excellent mechanical characteristics, especially excellent toughness, can easily be prepared.

Claims

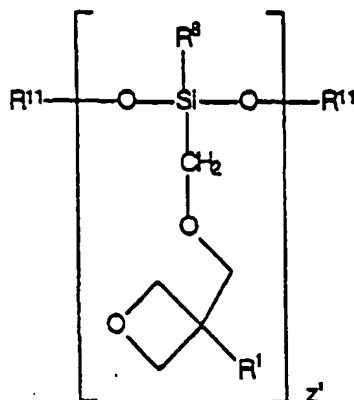
1. A process for photo-fabricating a three-dimensional object comprising selectively curing a photo-curable composition comprising an (A) oxetane compound, (B) an epoxy compound and (C) a cationic photo-initiator characterised in that the oxetane compound is a compound comprising two or more oxetane rings.
2. A process for photo-fabricating a three-dimensional object comprising selectively curing a photo-curable composition comprising an (A) oxetane compound, (B) an epoxy compound and (C) a cationic photo-initiator characterised in that the oxetane compound has one or more groups according to the formula:



wherein Z is oxygen or sulphur and wherein R¹ and R² constitute the remainder of a molecule.

3. The process according to claim 2, characterised in that the oxetane compound is selected from the group consisting of (3-ethyl-3-oxetanylmethoxy)methylbenzene, 1,4-bis[(3-ethyl-3-oxetanylmethoxy)-methyl]benzene, 1,2-bis(3-ethyl-3-oxetanylmethoxy)ethane, and trimethylolpropane tris(3-ethyl-3-oxetanylmethyl) ether.

4. The process according to claim 2, characterised in that the oxetane compound is a compound represented by formula (16)



wherein R^1 represents the remainder of a molecule, R^8 represents an alkyl group having from 1-4 carbon atoms such as a methyl, ethyl, propyl or butyl group, or an aryl group having from 6 to 18 carbon atoms such as a phenyl or naphthyl group, R^{11} represents an alkyl group having from 1 to 4 carbon atoms such as a methyl group, ethyl group, propyl group, butyl group, or a trialkylsilyl group, wherein the alkyl groups may be either the same or different and have from 3 to 12 carbon atoms, such as a trimethylsilyl group, triethylsilyl group, tripropylsilyl group, or tributylsilyl group, and z' is an integer from 1 to 10.

5. The process according to any one of claims 1-4, characterised in that the epoxy compound has a number average molecular weight of 1,000-20,000.

6. The process according to any one of claims 1-5, characterised in that the photo-curable composition comprises, relative to the total weight of the composition:

about 30-97% by weight of (A);
about 3-50% by weight of (B); and
about 0.1-10% by weight of (C).

7. The process according to any one of claims 1-6, characterised in that the composition further comprises a polyol.

8. The process according to claim 7, characterised in that the polyol is a polyether polyol having from 3 to 6 hydroxyl groups in one molecule.

9. The process according to any one of claims 1-8, characterised in that the composition further comprises an ethylenically unsaturated compound which is a radically polymerizable compound and a radical photo-initiator.

10. The process according to any one of claims 1-9, characterised in that the resin composition when cured has Young's Modulus of 80 kg/mm² or higher.

11. The process according to any one of claims 1-10, characterised in that said resin composition has substantially the same Young's Modulus when cured at an irradiation dose of 100 mJ/cm² and 500 mJ/cm².

12. The process according to any one of claims 1-11, characterised in that said resin composition has a difference in Young's Modulus, when cured at an irradiation dose of 100 mJ/cm² and 500 mJ/cm², of less than 10 kg/mm².

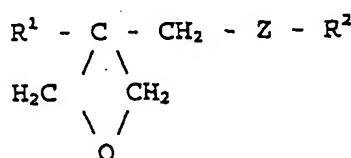
13. The process according to any one of claims 1-12, characterised in that the resin composition when cured has a tensile elongation of between about 10-40%.

14. A three-dimensional object comprising a cured photo-curable resin composition according to any one of claims 1-13.

Patentansprüche

1. Verfahren zum Photoherstellen eines dreidimensionalen Gegenstands, umfassend das selektive Härten einer photohärtbaren Zusammensetzung, welche (A) eine Oxetanverbindung, (B) eine Epoxidverbindung und (C) einen kationischen Photoinitiator umfaßt, **dadurch gekennzeichnet, daß** die Oxetanverbindung eine zwei oder mehrere Oxetanringe umfassende Verbindung ist.

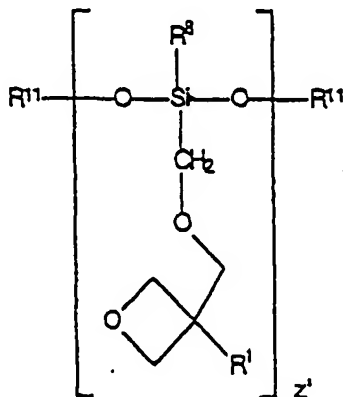
2. Verfahren zum Photoherstellen eines dreidimensionalen Gegenstands, umfassend das selektive Härten einer photohärtbaren Zusammensetzung, welche (A) eine Oxetanverbindung, (B) eine Epoxidverbindung und (C) einen kationischen Photoinitiator umfaßt, **dadurch gekennzeichnet, daß** die Oxetanverbindung eine oder mehrere Gruppen gemäß der Formel



aufweist, wobei Z Sauerstoff oder Schwefel ist und wobei R¹ und R² den Rest eines Moleküls darstellen.

3. Verfahren nach Anspruch 2, **dadurch gekennzeichnet, daß** die Oxetanverbindung aus der Gruppe ausgewählt ist, welche aus (3-Ethyl-3-oxetanyl-methoxy)methylbenzol, 1,4-Bis[(3-ethyl-3-oxetanylmethoxy)-methyl]benzol, 1,2-Bis(3-ethyl-3-oxetanylmethoxy)ethan und Trimethylolpropan-tris-(3-ethyl-3-oxetanylmethyl)ether besteht.

4. Verfahren nach Anspruch 2, **dadurch gekennzeichnet, daß** die Oxetanverbindung eine durch die Formel (16) dargestellte Verbindung ist



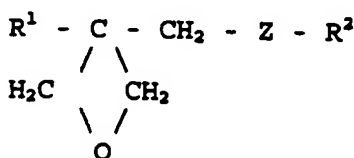
wobei R¹ den Rest eines Moleküls darstellt, R⁸ eine Alkylgruppe mit von 1 bis 4 Kohlenstoffatomen wie eine Methyl-, Ethyl-, Propyl- oder Butylgruppe oder eine Arylgruppe mit von 6 bis 18 Kohlenstoffatomen wie eine Phenyl- oder Naphthylgruppe ist, R¹¹ eine Alkylgruppe mit von 1 bis 4 Kohlenstoffatomen wie eine Methylgruppe, Ethylgruppe, Propylgruppe, Butylgruppe oder eine Trialkylsilylgruppe ist, wobei die Alkylgruppen entweder gleich oder verschieden sein können und von 3 bis 12 Kohlenstoffatomen aufweisen, wie eine Trimethylsilylgruppe, Triethyl-

silylgruppe, Tripropylsilylgruppe oder Tributylsilylgruppe, und z' eine ganze Zahl von 1 bis 10 ist.

- 5 5. Verfahren nach einem der Ansprüche 1 bis 4, **dadurch gekennzeichnet, daß** die Epoxidverbindung ein zahlen-
gemittelttes Molekulargewicht von 1 000 bis 20 000 aufweist.
6. Verfahren nach einem der Ansprüche 1 bis 5, **dadurch gekennzeichnet, daß** die photohärtbare Zusammenset-
zung etwa 30 bis 97 Gewichtsprozent (A), etwa 3 bis 50 Gewichtsprozent (B) und etwa 0,1 bis 10 Gewichtsprozent
(C), bezogen auf das Gesamtgewicht der Zusammensetzung, umfaßt.
- 10 7. Verfahren nach einem der Ansprüche 1 bis 6, **dadurch gekennzeichnet, daß** die Zusammensetzung ferner ein
Polyol umfaßt.
8. Verfahren nach Anspruch 7, **dadurch gekennzeichnet, daß** das Polyol ein Polyetherpolyol mit von 3 bis 6 Hy-
droxylgruppen in einem Molekül ist.
- 15 9. Verfahren nach einem der Ansprüche 1 bis 8, **dadurch gekennzeichnet, daß** die Zusammensetzung ferner eine
ethylenisch ungesättigte Verbindung, welche eine radikalisch polymerisierbare Verbindung ist, und einen radika-
lischen Photoinitiator umfaßt.
- 20 10. Verfahren nach einem der Ansprüche 1 bis 9, **dadurch gekennzeichnet, daß** die Harzzusammensetzung, wenn
sie gehärtet ist, einen Young'schen Elastizitätsmodul von 80 kg/mm² oder höher aufweist.
11. Verfahren nach einem der Ansprüche 1 bis 10, **dadurch gekennzeichnet, daß** diese Harzzusammensetzung im
wesentlichen den gleichen Young'schen Elastizitätsmodul aufweist, wenn sie mit einer Strahlungsdosis von 100
25 mJ/cm² und von 500 mJ/cm² gehärtet wurde.
12. Verfahren nach einem der Ansprüche 1 bis 11, **dadurch gekennzeichnet, daß** diese Harzzusammensetzung
einen Unterschied des Young'schen Elastizitätsmoduls von weniger als 10 kg/mm² aufweist, wenn sie mit einer
Strahlungsdosis von 100 mJ/cm² und von 500 mJ/cm² gehärtet wurde.
- 30 13. Verfahren nach einem der Ansprüche 1 bis 12, **dadurch gekennzeichnet, daß** die Harzzusammensetzung, wenn
sie gehärtet ist, eine Zugausdehnung von zwischen etwa 10 bis 40% aufweist.
14. Dreidimensionaler Gegenstand, umfassend eine gehärtete photohärtbare Harzzusammensetzung nach einem der
35 Ansprüche 1 bis 13.

Revendications

- 40 1. Procédé pour la photofabrication d'un objet tridimensionnel comprenant le durcissement sélectif d'une composition
photodurcissable comprenant un (A) composé oxétane, (B) un composé époxy et (C) un photoinitiateur cationique,
caractérisé en ce que le composé oxétane est un composé comprenant deux cycles oxétane ou plus.
- 45 2. Procédé pour la photofabrication d'un objet tridimensionnel comprenant le durcissement sélectif d'une composition
photodurcissable comprenant un (A) composé oxétane, (B) un composé époxy et (C) un photoinitiateur cationique,
caractérisé en ce que le composé oxétane a un ou plusieurs groupes selon la formule :

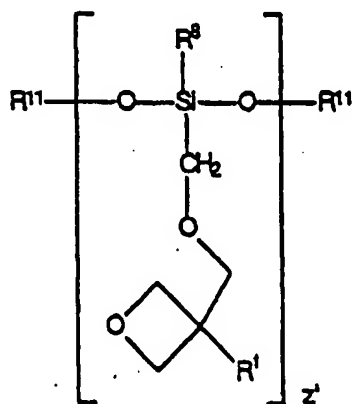


dans laquelle Z est un atome d'oxygène ou de soufre, et dans laquelle R¹ et R² constituent le reste d'une molécule.

3. Procédé selon la revendication 2, caractérisé en ce que le composé oxétane est choisi parmi le (3-éthyl-3-oxé-

tanylméthoxy)méthylbenzène, le 1,4-bis[(3-éthyl-3-oxétanylméthoxy)-méthyl]benzène, le 1,2-bis(3-éthyl-3-oxétanylméthoxy)éthane, et le triméthylolpropane tris(3-éthyl-3-oxétanyl)éther.

4. Procédé selon la revendication 2, caractérisé en ce que le composé oxétane est un composé représenté par la formule (16)



dans laquelle R¹ représente le reste d'une molécule, R⁸ représente un groupe alkyle ayant de 1 à 4 atomes de carbone tel qu'un groupe méthyle, éthyle, propyle ou butyle, ou un groupe aryle ayant de 6 à 18 atomes de carbone tel qu'un groupe phényle ou naphthyle, R¹¹ représente un groupe alkyle ayant de 1 à 4 atomes de carbone tel qu'un groupe méthyle, un groupe éthyle, un groupe propyle, un groupe butyle ou un groupe trialkylsilyle, dans lequel les groupes alkyle peuvent être identiques ou différents et avoir de 3 à 12 atomes de carbone, tel qu'un groupe triméthylsilyle, un groupe triéthylsilyle, un groupe tripropylsilyle, ou un groupe tributylsilyle, et z' est un entier compris entre 1 et 10.

5. Procédé selon l'une quelconque des revendications 1-4, caractérisé en ce que le composé époxy a une masse moléculaire moyenne en nombre comprise entre 1000 et 20000.

6. Procédé selon l'une quelconque des revendications 1-5, caractérisé en ce que la composition photodurcissable comprend, par rapport au poids total de la composition :

environ 30-97% en poids de (A) ;
environ 3-50% en poids de (B) ; et
environ 0,1-10% en poids de (C).

7. Procédé selon l'une quelconque des revendication 1 à 6, caractérisé en ce que la composition comprend en outre un polyol.

8. Procédé selon la revendication 7, caractérisé en ce que le polyol est un polyéther-polyol ayant entre 3 et 6 groupes hydroxyle dans une molécule.

9. Procédé selon l'une quelconque des revendications 1 à 8, caractérisé en ce que la composition comprend en outre un composé éthyléniquement insaturé qui est un composé polymérisable par voie radicalaire et un photoinitiateur radicalaire.

10. Procédé selon l'une quelconque des revendications 1 à 9, caractérisé en ce que la composition de résine après durcissement a un module d'Young de 80 kg/mm² ou plus.

11. Procédé selon l'une quelconque des revendications 1 à 10, caractérisé en ce que ladite composition de résine a pratiquement le même module d'Young lorsqu'elle est durcie à une dose d'irradiation de 100 mJ/cm² et de 500 mJ/cm².

EP 0 848 294 B1

12. Procédé selon l'une quelconque des revendications 1 à 11, caractérisé en ce que ladite composition de résine a une différence dans le module d'Young, lorsqu'elle est durcie à une dose d'irradiation de 100 mJ/cm² et de 500 mJ/cm², de moins de 10 kg/mm².

5 13. Procédé selon l'une quelconque des revendications 1 à 12, caractérisé en ce que la composition de résine a, après durcissement, un allongement en traction compris entre environ 10 et 40%.

14. Objet tridimensionnel comprenant une composition de résine photodurcissable durcie selon l'une quelconque des revendications 1 à 13.

10

15

20

25

30

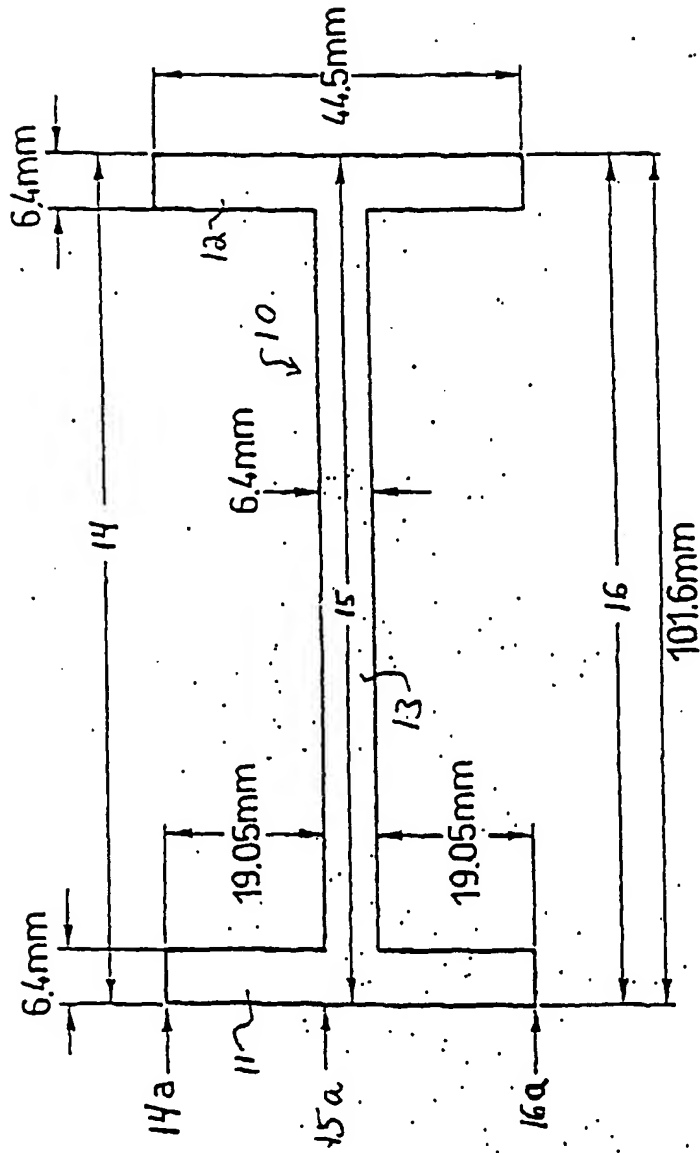
35

40

45

50

55



FIGURE